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REVIEW

# Phytochemistry and pharmacological activities of the genus *Rhynchosia*: a comprehensive review

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## Abstract

***Main conclusion*** **The genus *Rhynchosia* is a rich source of natural compounds especially flavonoids and prenylated isoflavonoids. Further experimental studies on *Rhynchosia* members may be result new and novel secondary metabolites with potent biological activities.**

**Abstract** Traditionally, medicinal plants have played a significant role on human life since ancient days. At present, natural compounds are the major source for the modern drug discovery owing to their therapeutic selectivity, minutest of side effects, inexpensive source and serve as lead molecules for the discovery of new drugs. *Rhynchosia* species (Fabaceae) are extensively circulated throughout the tropical and subtropical areas around the world. A few plants of this genus were used in traditional medicine for the treatment of various ailments such as antibacterial, antidiabetic, abortifacients, healing of wounds, hepatoprotective, remedial of boils, rheumatic pains and skin infections. The present review compiles traditional uses, isolated chemical compounds and pharmacological activities of *Rhynchosia* species. So far, in total, seventy-seven compounds were isolated from the genus *Rhynchosia*, including flavonoids, isoflavonoids, flavan-3-ols, xanthones, biphenyls, simple polyphenols and sterols. It is interesting to note that the genus *Rhynchosia* is a rich source of *C*-glycosylflavonoids and prenylated isoflavonoids. Further, phytochemical and pharmacological studies on this genus are required since only few species have been investigated so far.

**Keywords** Flavonoids · Phytochemistry · Pharmacology · *Rhynchosia* · Traditional medicine

## Introduction

Medicinal plants are worthy source of biologically active compounds for the development of new therapeutic drug candidates over the past centuries (Harvey 2008; Koehn and Carter 2005; Newman and Cragg 2012). Plants are treasure house of bioactive compounds which can be developed as safe drugs for the treatment of various human diseases. It is the time to recall the significance and past invention of some of the most illustrative examples of successful and promising drugs from natural source are listed. Aspirin: an anti-inflammatory agent (Newman et al. 2000); Digitoxin: used as a drug for congestive heart failure (Buss et al. 2003); Morphine: is a commercial drug and its derivative apomorphine used to treat Parkinson′s disease (Dias et al. 2012); Penicillin: an important antibacterial agent (Wainwright 1990), Quinine: the anti-malarial drug (Achan et al. 2011); Taxol: promising anticancer drug (Kingston 1993), etc. are

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still used for therapeutic applications. Even today, people in several countries are extensively using plant species as a remedy for the treatment of various kinds of diseases such as bacterial infections, cardiovascular, diabetic, digestive, kidney, mental-nervous, nutritional, respiratory, reproductive, sensory, skin infections and several wounds (González-Tejero et al. 2008). Thus, the plants have valuable source of natural compounds and played significant role in the current drug discovery with clinically enriched efficacy besides fewer side effects (Butler 2004). Hence, many researchers have been focusing their research interest on medicinal plants in terms of biological activity and drug discovery.

Among the plants of Fabaceae family which are used in traditional medicine, *Rhynchosia* species have occupied a prominent role. *Rhynchosia* genus consists of approximately 300 species circulated throughout the tropical and subtropical areas around the world, out of which twenty-two species occur in India (Chadha 1976; Willis 1966). The species belonging to the genus *Rhynchosia* (Fabaceae) are herbs, twining or erect shrubs. Previous phytochemical investigations on several species of *Rhynchosia* showed that the genus is exclusive to profuse production of *C*-glycosylflavonoids (Rao et al. 1991). Some of the isolated compounds of *Rhynchosia* genus and their plant extracts exhibit interesting biological activities, including antioxidant, anti-inflammatory, antimycobacterial and antiproliferative (Coronado-Aceves et al. 2017; Kinjo et al. 2001; Rondo 2017). A tiny review on chemical constituents of *Rhynchosia genus* was published in 1991 from our laboratory (Rao et al. 1991); however, the review covers only few phytochemistry reports but not on pharmacology perspective. To the best of our knowledge, no comprehensive, updated phytochemical and pharmacology review was published on *Rhynchosia* species which covers the literature up to date. The present review aimed to deliver an outline on the traditional uses, chemical constituents and pharmacology activities of the genus *Rhynchosia* which includes the literature up to date for future research opportunities.

## Traditional uses

Based on folkloric medications, a few plants of *Rhynchosia* genus were used in indigenous medicine (Bakshu and Raju 2001; Bangalore and Agrahari 2009; Gamble and Fischer 1935; Kritikar and Basu 1975) such as antibacterial, antidiabetic, abortifacients, healing of wounds, hepatoprotective, rheumatic pains, remedial for boils and skin infections by Adivasi tribes. For example, *Rhynchosia scarabaeiods* L. (known as 'gadi chikkudu kaya') has been used to treat various bacterial diseases like dysentery, diarrhea and skin infections (Challa et al. 2011). Another endemic species of South India, *Rhynchosia suaveolens* DC is reported as antioxidant and antibacterial agent (Khan and Shoeb 1984; Rammohan et al. 2015). The whole plant of *Rhynchosia pseudo-cajan* Cambess is widely distributed in Pakistan and is used to treat oxidative stress through antioxidant principles (Riaz et al. 2011). Roots of some species of *Rhynchosia* genus have bacterial nodules which enrich soil and may be useful for the agricultural practices (Chadha 1976). Seeds of some *Rhynchosia* members are said to have bitter and toxic drug properties but occasionally consumed by certain South Mexican Indian tribes as analgesics (Allen and Allen 1981). The species *Rhynchosia volubilis* has been reported as property of antiproliferative (Kinjo et al. 2001) and *Rhynchosia villosa* showed tyrosinase enzyme inhibitory activity (Rondo 2017). In addition, *R. volubilis* is used by Koreans as local cosmetics which has a property of depigmenting the skin stains, treating the skin wrinkles and anti-aging (Li and Xiang 2011). Likewise, the leaves of *Rhynchosia beddomei* were found to be antidiabetic (Mary et al. 2014), *Rhynchosia precatoria* roots exhibits antimycobacterial activity (Coronado-Aceves et al. 2017) and the *Rhynchosia pyramidalis* has androgenic and aphrodisiac action (Farnsworth et al. 1967). The essential oil isolated from the leaves of *Rhynchosia heynei* and *Rhynchosia minima* showed broad spectrum of antimicrobial (Bakshu and Raju 2009; Gweru et al. 2009), antioxidant activities (Gweru et al. 2009) and allelopathy activity (Abd ElGawad et al. 2018). Therefore, the development of drug agents from natural origin is of great importance, based on the traditional and pharmacological uses of the genus *Rhynchosia*.

Table 6 represents the reported traditional uses of *Rhynchosia* species used for treating various ailments. These documented data represent that most of the species are used to treat oxidative stress-related (antioxidants), antibacterial, anti-inflammation and skin disorders. Also, they are used as analgesic and for the digestive disorders.

## Phytochemistry

In the past few decades, some *Rhynchosia* species have been investigated from a phytochemical and pharmacological point of view. So far, in total, seventy-seven compounds were isolated; their structures, names and the corresponding plant source are compiled in Tables 1, 2, 3, 4, 5 and Figs. 1, 2, 3, 4, 5, 6, 7, 8, 9. A comprehensive of chemical constituents so far reported from the genus *Rhynchosia* can be conveniently grouped into the following types.

### Flavones and flavone glycosides

Fifteen compounds (**1**–**15**, Fig. 1) were isolated from the genus *Rhynchosia* so far. Among them, most of the reported *C*-glycosylflavones are derivatives of apigenin and luteolin.

**Table 1** Naturally occurring flavones and flavone glycosides of the genus *Rhynchosia*

| Compounds/trivial names | Plant source | Plant part | References |
|---|---|---|---|
| Apigenin (**1**) | *R. beddomei* | Leaves | Adinarayana et al. (1985) |
| | *R. heynei* | Leaves | Adinarayana et al. (1985) |
| | *R. rothii* | Leaves | Rao and Gunasekar (1987) |
| Luteolin (**2**) | *R. heynei* | Leaves | Adinarayana et al. (1985) |
| | *R. suaveolens* | Leaves | Adinarayana et al. (1985) |
| Tricin (**3**) | *R. volubilis* | Roots | Li and Xiang (2011) |
| Apigenin-7-*O*-*β*-D-glucopyranoside (**4**) | *R. volubilis* | Roots | Li and Xiang (2011) |
| Luteolin-7-*O*-*β*-D-glucopyranoside (**5**) | *R. volubilis* | Roots | Li and Xiang (2011) |
| 3′,4′-Di-*O*-methylluteolin-7-*O*-glucuronide (**6**) | *R. beddomei* | Leaves | Adinarayana et al. (1980b) |
| Vitexin (**7**) | *R. beddomei* | Leaves | Adinarayana et al. (1980b) |
| | *R. rufescens* | Leaves | Adinarayana et al. (1979) |
| | *R. bracteata* | Leaves | Ali et al. (1992) |
| | *R. sublobata* | Leaves | Ali et al. (1992) |
| | *R. cana* | Leaves | Adinarayana and Ramachandraiah (1986) |
| | *R. capitata* | Leaves | Praveena et al. (2013) |
| | *R. heynei* | Leaves | Adinarayana et al. (1985) |
| | *R. minima* | Leaves | Adinarayana et al. (1985) |
| | *R. sericea* | Leaves | Adinarayana et al. (1985) |
| | *R. suaveolens* | Leaves | Adinarayana and Ramachandraiah (1985) |
| | *R. jacobii* | Leaves | Seetharamamma et al. (1989) |
| Isovitexin (**8**) | *R. beddomei* | Leaves | Adinarayana et al. (1980b) |
| | *R. beddomei* | Flowers | Rammohan et al. (2019) |
| | *R. rufescens* | Leaves | Adinarayana et al. (1979) |
| | *R. bracteata* | Leaves | Ali et al. (1992) |
| | *R. sublobata* | Leaves | Ali et al. (1992) |
| | *R. cana* | Leaves | Adinarayana and Ramachandraiah (1986) |
| | *R. capitata* | Leaves | Praveena et al. (2013) |
| | *R. heynei* | Leaves | Adinarayana et al. (1985) |
| | *R. minima* | Leaves | Adinarayana et al. (1985) |
| | *R. sericea* | Leaves | Adinarayana et al. (1985) |
| | *R. rothii* | Leaves | Rao and Gunasekar (1987) |
| | *R. suaveolens* | Leaves | Adinarayana et al. (1985) |
| | | Flowers | Rammohan et al. (2015) |
| | *R. jacobii* | Leaves | Seetharamamma et al. (1989) |
| Vicenin-1 (**9**) | *R. jacobii* | Leaves | Seetharamamma et al. (1989) |
| Vicenin-2 (**10**) | *R. beddomei* | Leaves | Adinarayana et al. (1980b) |
| | *R. rufescens* | Leaves | Adinarayana et al. (1979) |
| | *R. bracteata* | Leaves | Ali et al. (1992) |
| | *R. sublobata* | Leaves | Ali et al. (1992) |
| | *R. cana* | Leaves | Adinarayana and Ramachandraiah (1986) |
| | *R. capitata* | Leaves | Adinarayana et al. (1985) |
| | *R. heynei* | Leaves | Adinarayana et al. (1985) |
| | *R. jacobii* | Leaves | Seetharamamma et al. (1989) |
| | *R. minima* | Leaves | Adinarayana et al. (1985) |
| | *R. rothii* | Leaves | Rao and Gunasekar (1987) |
| | *R. sericea* | Leaves | Adinarayana et al. (1985) |
| | *R. suaveolens* | Leaves | Adinarayana et al. (1985) |
| Vicenin-3 (**11**) | *R. minima* | Leaves | Besson et al. (1977) |
| | *R. sericea* | Leaves | Adinarayana et al. (1985) |
| Schaftoside (**12**) | *R. minima* | Leaves | Besson et al. (1977) |

**Table 1** (continued)

| Compounds/trivial names | Plant source | Plant part | References |
|---|---|---|---|
| Orientin (**13**) | *R. beddomei* | Leaves | Adinarayana et al. (1980b) |
| | *R. rufescens* | Leaves | Adinarayana et al. (1979) |
| | *R. bracteata* | Leaves | Ali et al. (1992) |
| | *R. sublobata* | Leaves | Ali et al. (1992) |
| | *R. cana* | Leaves | Adinarayana and Ramachandraiah (1986) |
| | *R. capitata* | Leaves | Adinarayana et al. (1985) |
| | *R. heynei* | Leaves | Adinarayana et al. (1985) |
| | *R. jacobii* | Leaves | Seetharamamma et al. (1989) |
| | *R. minima* | Leaves | Adinarayana et al. (1985) |
| | *R. rothii* | Leaves | Rao and Gunasekar (1987) |
| | *R. sericea* | Leaves | Adinarayana et al. (1985) |
| | *R. suaveolens* | Leaves | Adinarayana et al. (1985) |
| Isoorientin (**14**) | *R. beddomei* | Leaves | Adinarayana et al. (1979) |
| | *R. beddomei* | Flowers | Rammohan et al. (2019) |
| | *R. rufescens* | Leaves | Adinarayana et al. (1979) |
| | *R. bracteata* | Leaves | Ali et al. (1992) |
| | *R. sublobata* | Leaves | Ali et al. (1992) |
| | *R. cana* | Leaves | Adinarayana and Ramachandraiah (1986) |
| | *R. capitata* | Leaves | Praveena et al. (2013) |
| | *R. heynei* | Leaves | Adinarayana et al. (1985) |
| | *R. jacobii* | Leaves | Seetharamamma et al. (1989) |
| | *R. minima* | Leaves | Adinarayana et al. (1985) |
| | *R. rothii* | Leaves | Rao and Gunasekar (1987) |
| | *R. sericea* | Leaves | Adinarayana et al. (1985) |
| | *R. suaveolens* | Leaves | Adinarayana et al. (1985) |
| | *R. suaveolens* | Flowers | Rammohan et al. (2015) |
| Lucenin-2 (**15**) | *R. beddomei* | Leaves | Adinarayana et al. (1980a) |
| | *R. rufescens* | Leaves | Adinarayana et al. (1979) |
| | *R. bracteata* | Leaves | Ali et al. (1992) |
| | *R. sublobata* | Leaves | Ali et al. (1992) |
| | *R. heynei* | Leaves | Adinarayana et al. (1985) |
| | *R. rothii* | Leaves | Rao and Gunasekar (1987) |

**Table 2** Naturally occurring flavonols and flavonol glycosides of the genus *Rhynchosia*

| Compounds/trivial names | Plant source | Plant part | References |
|---|---|---|---|
| Kaempferol (**16**) | *R. volubilis* | Roots | Li and Xiang (2011) |
| Quercetin (**17**) | *R. volubilis* | Roots | Li and Xiang (2011) |
| Kaempferol-3-*O*-methylether (**18**) | *R. rufescens* | Leaves | Adinarayana and Ramachandraiah (1984) |
| Kaempferol-3-*O*-rutinoside (**19**) | *R. cyanosperma* | Leaves | Adinarayana et al. (1980a) |
| Quercetin-3-*O*-methylether (**20**) | *R. rufescens* | Leaves | Adinarayana and Ramachandraiah (1984) |
| Quercetin-7-*O*-methylether (**21**) | *R. beddomei* | Flowers | Rammohan et al. (2019) |
| Rutin (**22**) | *R. beddomei* | Leaves | Adinarayana et al. (1980b) |
| | *R. cyanosperma* | Leaves | Adinarayana et al. (1980a) |
| Rhynchosin (**23**) | *R. beddomei* | Leaves | Adinarayana et al. (1980c) |
| Rhynchospermin (**24**) | *R. cyanosperma* | Leaves | Adinarayana et al. (1981) |

**Table 3** Naturally occurring dihydroflavonols of the genus *Rhynchosia*

| Compounds/Trivial Names | Plant Source | Plant part | References |
|---|---|---|---|
| Tirumalin (**27**) | *R. cyanosperma* | Leaves | Adinarayana et al. (1980a) |
| Isotirumalin (**28**) | *R. cyanosperma* | Leaves | Rao and Gunasekar (1988) |
| 6-*C*-Prenyltoxifolin-7,3′-dimethylether (**29**) | *R. densiflora* | Leaves | Rao and Gunasekar (1998) |
| Lupinifolinol (**30**) | *R. precatoria* | Roots | Coronado-Aceves et al. (2017) |

**Table 4** Naturally occurring isoflavones and isoflavanones of the genus *Rhynchosia*

| Compounds/trivial names | Plant source | Plant part | References |
|---|---|---|---|
| Diadzein (**31**) | *R. volubilis* | Roots | Li and Xiang (2011) |
| Calycosin (**32**) | *R. volubilis* | Roots | Li and Xiang (2011) |
| Genistein (**33**) | *R. viscosa* | – | Bohni et al. (2013) |
| | *R. villosa* | Roots | Rondo (2017) |
| Biochanin A (**34**) | *R. volubilis* | Roots | Li and Xiang (2011) |
| | *R. beddomei* | Flowers | Rammohan et al. (2019) |
| 2′-Hydroxygenistein (**35**) | *R. villosa* | Roots | Rondo (2017) |
| 3′-O-Methylorobol (**36**) | *R. viscosa* | – | Bohni et al. (2013) |
| 3′-Hydroxybiochanin A (**37**) | *R. volubilis* | Roots | Li and Xiang (2011) |
| Cajanin (**38**) | *R. villosa* | Roots | Rondo (2017) |
| Licoisoflavone A (**39**) | *R. viscosa* | – | Bohni et al. (2013) |
| 4′-(1″-Methoxy)-propylgenistein (**40**) | *R. volubilis* | Roots | Li and Xiang (2011) |
| Rhynedulin A (**41**) | *R. edulis* | Bark | Guo et al. (2011) |
| Rhynedulin B (**42**) | *R. edulis* | Bark | Guo et al. (2011) |
| Rhynedulin C (**43**) | *R. edulis* | Bark | Guo et al. (2011) |
| Cyclochandalone (**44**) | *R. edulis* | Bark | Guo et al. (2011) |
| Ulexin B (**45**) | *R. edulis* | Bark | Guo et al. (2011) |
| Rhynedulinal (**46**) | *R. edulis* | Bark | Guo et al. (2011) |
| Scandelinal (**47**) | *R. edulis* | Bark | Guo et al. (2011) |
| Cajanone (**48**) | *R. precatoria* | Roots | Coronado-Aceves et al. (2017) |
| | *R. volubilis* | – | Bohni et al. (2013) |
| | *R. edulis* | Bark | Guo et al. (2011) |
| Precatorin C (**49**) | *R. precatoria* | Roots | Coronado-Aceves et al. (2017) |
| Sophoraisoflavone A (**50**) | *R. viscosa* | – | Bohni et al. (2013) |
| Precatorin A (**51**) | *R. precatoria* | Roots | Coronado-Aceves et al. (2017) |
| Precatorin B (**52**) | *R. precatoria* | Roots | Coronado-Aceves et al. (2017) |
| Rhynchoviscin (**53**) | *R. viscosa* | – | Bohni et al. (2013) |

"-" Indicates plant part not mentioned in publication

## Flavonols and flavonol glycosides

Till now, only eight flavonols (**16**–**24**, Fig. 2) were reported from the species of *Rhynchosia*. Except compound **23**, all the flavonols and flavonol glycosides reported in the genus *Rhynchosia* are the derivatives of kaempferol and quercetin. An interesting note that Rhynchosin (**23**), is the only 5-deoxyflavnol is isolated from the leaves of *Rhynchosia beddomei* (Adinarayana et al. 1980c) up to now in the genus *Rhynchosia*.

## Flavanones

Naringenin (**25**) and lupinifolin (**26**) were isolated from the leaves of *Rhynchosia beddomei* and the roots of *Rhynchosia precatoria*, respectively (Adinarayana et al. 1979; Coronado-Aceves et al. 2017), which are the only two flavanones so far reported in this genus (Fig. 3).

**Table 5** Naturally occurring simple phenolic compounds of the genus *Rhynchosia*

| Compounds/trivial names | Plant source | Plant part | References |
|---|---|---|---|
| Protocatechuic acid (**62**) | *R. minima* | Pericaps | Krishnamurty et al. (1975) |
| Gallic acid (**63**) | *R. volubilis* | Seeds | Kinjo et al. (2001) |
| | *R. minima* | Pericaps | Krishnamurty et al. (1975) |
| Vanillic acid (**64**) | *R. suaveolens* | Leaves | Adinarayana et al. (1985) |
| | *R. cyanosperma* | Leaves | Adinarayana et al. (1980a) |
| Ethyl gallate (**65**) | *R. minima* | Pericaps | Krishnamurty et al. (1975) |
| Methyl gallate (**66**) | *R. volubilis* | Seeds | Kinjo et al. (2001) |
| Glucogallin (**67**) | *R. volubilis* | Seeds | Kinjo et al. (2001) |
| 1,6-Di-*O*-galloylglucose (**68**) | *R. volubilis* | Seeds | Kinjo et al. (2001) |
| Trigalloylgallic acid (**69**) | *R. volubilis* | Seeds | Kinjo et al. (2001) |
| 2-Hydroxy-3,4-dimethoxybenzophenone (**70**) | *R. suaveolens* | Flowers | Rammohan et al. (2015) |
| Hydroquinone Diacetate (**71**) | *R. minima* | Pericaps | Krishnamurty et al. (1975) |
| D-Pinitol (**72**) | *R. beddomei* | Leaves | Adinarayana et al. (1979) |
| | *R. cyanosperma* | Leaves | Adinarayana et al. (1980a) |
| D-inositol (**73**) | *R. beddomei* | Leaves | Adinarayana et al. (1980c) |

## Dihydroflavonols

Only four dihydroflavonols (**27**–**30**, Fig. 4) are reported in the genus *Rhynchosia* and all the listed compounds are *C*-prenylated derivatives. Also, the compounds **27**–**29** were reported as new dihyroflavols from the species *R. cyanosperma* (Adinarayana et al. 1980a; Rao and Gunasekar 1988) and *R. densiflora* (Rao and Gunasekar 1998).

## Isoflavones and Isoflavanones

A total of nineteen isoflavones (**31**–**49**, Fig. 5) and three isoflavanones (**50**–**53**) to date were reported from the genus *Rhynchosia*. Most of the isoflavones isolated from the species *R. edulis* (Ogungbe et al. 2011) are substituted with either prenyl or dimethylpyrano group in both ring A and ring B, except in **46** and **47** in which prenylation in ring B is absent. Two isoflavone derivatives, rhynedulinal (**46**) and candelinal (**47**) are isolated from *R. edulis* which have an unusual formyl group at 3′-position. Furthermore, two new isoflavanones reported as precatorin A (**50**) and B (**51**) from the roots of *R. precatoria* (Coronado-Aceves et al. 2017) are structural isomers, as they differed only in the location of dimethylpyrene ring fusion in an ring A of isoflavanoid moiety. An unusual method was attempted using 1-butyl-3-methyl tetrafluoroborate ionic liquid for the isolation of isoflavones such as biochanin A (**34**), 4′-(1″-methoxy)-propoylgenistein (**40**) and cajanone (**48**) from the *Rhynchosia volubilis* (Ogungbe et al. 2011) and this report was very typical compared with conventional methods. This approach for the extraction and isolation of flavonoids using ionic liquids is environmental benign and green method. An unusual new isoflavanoid derivative, Rhynchoviscin (**53**) reported from *R. viscosa* with novel skeleton basis of benzodihydrofuran moiety fused with benzodihydropyran ring, was established with 2D NMR spectral studies. The isolation of compound **53** is achieved through Zebrafish bioassay-guided microfractionation (Bohni et al. 2013) and this report is unique in this genus.

### Flavan-3-ols

Catechin (**54**) (Rondo 2017), epicatechin (**55**) (Li and Xiang 2011), 7-*O*-galloylcatechin (**56**) (Kinjo et al. 2001) and proanthocyanidin (**57**) (Rangaswamy et al. 1974), are the four flavan-3-ols (Fig. 6) so far isolated from various *Rhynchosia* species.

### Other phenolic compounds

These are non-flavonoid class simple polyphenolic compounds and listed below.

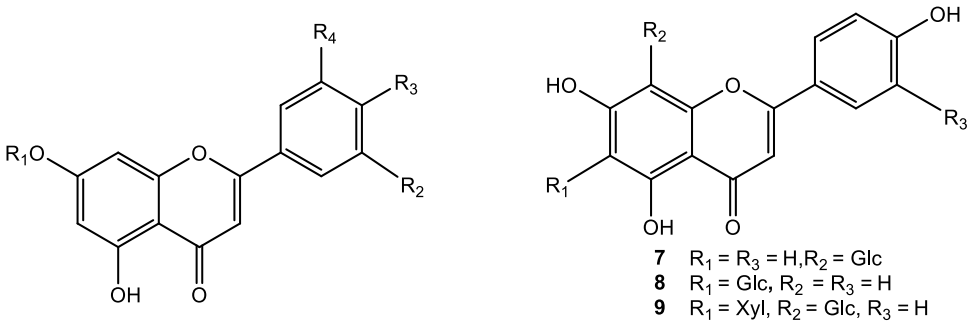
### Xanthones

Besides the above revealed flavonoids, two xanthone-*C*-glycosides (Fig. 7), mangiferin (**58**) and isomangiferin (**59**) (Adinarayana and Chetty 1985; Rammohan et al. 2015) have been isolated from *R. suaveolens*. It is expected that the co-occurrence *C*-glycosylflavonoids and *C*-glycosylxanthones in the same source *R. suaveolens* is due to chemotaxonomic prominence.

**Table 6** Scientific names and traditional uses of studied plants of the genus *Rhynchosia*

| No. | Plant name | Distribution | Traditional uses | References |
|---|---|---|---|---|
| 1. | *R. beddomei* Baker | India | Antioxidant, antidiabetic, anti-inflammatory, antimicrobial, analgesic, diuretic activity, rheumatic pains and remedial for wounds and boils | Bakshu and Raju (2001), Rammohan et al. 2019 |
| 2. | *R. bracteata* Benth | India | – | Gamble and Fischer (1935) |
| 3. | *R. cana* DC. | India | – | Adinarayana et al. (1985); Kritikar and Basu (1975) |
| 4. | *R. capitata* DC. | India, Pakistan | Antioxidant, constipation, gastric problems | Praveena et al. (2013) |
| 5. | *R. cyanosperma* Benth. | India | – | Gamble and Fischer (1935) |
| 6. | *R. densiflora* (Roth) DC. | India | – | Gamble and Fischer (1935) |
| 7. | *R. edulis* | India | Antiproliferative activity | Ogungbe et al. (2011) |
| 8. | *R. heynei* Wt. & Arn. | India | Antimicrobial, Arthritis and rheumatic pains, skin disorders | Bakshu and Raju (2009) |
| 9. | *R. jacobii* | India | – | Gamble and Fischer (1935) |
| 10. | *R. minima* (L.) DC. | Africa, India, Sri Lanka and USA | Antimicrobial, Antioxidant, Anthelmintic, Allelopathic activity | Abd ElGawad et al. (2018), Gweru et al. (2009) |
| 11. | *R. pseudo-cajan* Cambess | Pakistan | Antioxidant | Riaz et al. (2011) |
| 12. | *R. precatoria* (Humb. & Bonpl. Ex Willd.) DC. | North America | Antimycobacterial activity | Coronado-Aceves et al. (2017) |
| 13. | *R. pyramidalis* (*synm*: pega palo) | | Androgenic and aphrodisiac action | Farnsworth et al. (1967) |
| 14. | *R. rothii* | India | – | Adinarayana et al. (1985), Kritikar and Basu 1975 |
| 15. | *R. rufescens* DC. | India | – | Gamble and Fischer (1935) |
| 16. | *R. scarabaeoides* (L.) DC. | India | Antibacterial, Diarrhea, dysentery and skin infections | Challa et al. (2011) |
| 17. | *R. sericea* Span. | India | – | Gamble and Fischer (1935) |
| 18. | *R. sublobata* (Schumach.) | India | – | Adinarayana et al. (1985), Kritikar and Basu 1975 |
| 19. | *R. suaveolens* DC. | India | Antioxidant, antibacterial agent, abortifacients | Rammohan et al. (2015), Khan and Shoeb (1984), Kritikar and Basu (1975) |
| 20. | *R. villosa* | Africa | Tyrosinase enzyme inhibitory activity | Rondo (2017) |
| 21. | *R. viscosa* (Roth) DC. | Africa | Antinflammatory, Anti-angiogenic, Inflammatory skin disorders | Bohni et al. (2013) |
| 22. | *R. volubilis* Lour. | Japan, Korea | Antiproliferative, Anti-aging agent | Kinjo et al. (2001), Rondo (2017) |

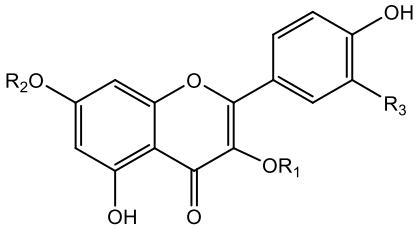
"-" Symbol indicates no significant traditional uses and activity studies are acknowledged



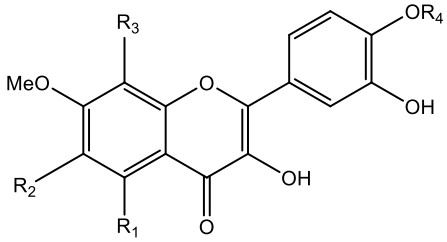

**1** $R_1 = R_2 = R_4 = H$, $R_3 = OH$
**2** $R_1 = R_4 = H$, $R_2 = R_3 = OH$
**3** $R_1 = H$,$R_2 = R_4 = OMe$,$R_3 = OH$
**4** $R_1 = \beta$-Glc, $R_2 = R_4 = H$, $R_3 = OH$
**5** $R_1 = \beta$-Glc, $R_2 = R_3 = OH$, $R_4 = H$
**6** $R_1 = \beta$-Glur, $R_2 = R_3 = OMe$, $R_4 = H$

**7** $R_1 = R_3 = H$,$R_2$ = Glc
**8** $R_1$ = Glc, $R_2 = R_3 = H$
**9** $R_1$ = Xyl, $R_2$ = Glc, $R_3 = H$
**10** $R_1 = R_2$ = Glc, $R_3 = H$
**11** $R_1$ = Glc, $R_2$= Xyl, $R_3 = H$
**12** $R_1$ = Glc, $R_2$ = Ara, $R_3 = H$
**13** $R_1 = H$, $R_2$ = Glc, $R_3 = OH$
**14** $R_1$ = Glc, $R_2 = H$, $R_3 = OH$
**15** $R_1 = R_2$ = Glc, $R_3 = OH$

**Fig. 1** Flavones and flavone glycosides (**1**–**15**) isolated from the genus *Rhynchosia*

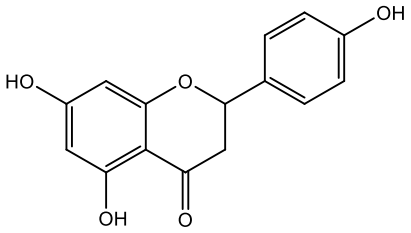



**16** $R_1 = R_2 = R_3 = H$
**17** $R_1 = R_2 = H, R_2 = OH$
**18** $R_1 = Me, R_2 = R_3 = H$
**19** $R_1 = Rha\text{-}Glc, R_2 = R_3 = H$
**20** $R_1 = Me, R_2 = H, R_3 = OH$
**21** $R_1 = H, R_2 = Me, R_3 = OH$
**22** $R_1 = Rha\text{-}Glc, R_2 = OH$

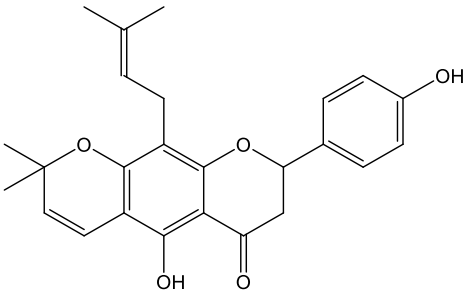



**23** $R_1 = R_3 = R_4 = H, R_2 = OH,$
**24** $R_1 = OH, R_2 = H, R_3 = Pre, R_4 = Me$

**Fig. 2** Flavanol and flavonol glycosides (**16**–**24**) isolated from the genus *Rhynchosia*

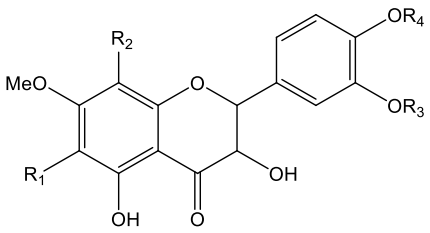



**25**

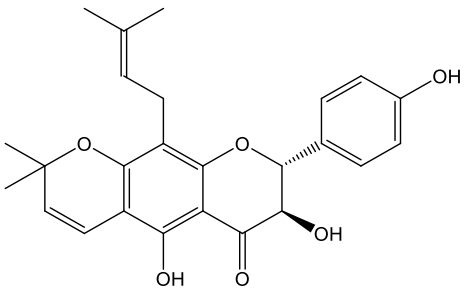



**26**

**Fig. 3** Flavanones (**25**–**26**) isolated from the genus *Rhynchosia*




**27** $R_1 = R_3 = H, R_2 = Pre, R_4 = Me$
**28** $R_1 = Pre, R_2 = R_3 = H, R_4 = Me$
**29** $R_1 = Pre, R_2 = R_4 = H, R_3 = Me$




**30**

**Fig. 4** Dihydroflavonols (**27**–**30**) isolated from the genus *Rhynchosia*

## Biphenyls

Two new biphenyls, 4-(3-methyl-but-2-enyl)-5-methoxy-(1,1′-biphenyl)-3-ol (**60**) and 2-carboxyl-4-(3-methyl-but-2-enyl)-5-methoxy-(1,1′-biphenyl)-3-ol (**61**) were isolated from the whole plant of *R. suaveolens* (Khan and Shoeb 1984, Fig. 7). The existence of biphenyls in plants was believed that the aldol-type condensation of shikimate derived *β*-triketo ester.

## Simple polyphenols

Twelve simple polyphenolic compounds (**62**–**73**, Fig. 8) such as gallic acid (**63**), vanillic acid (**64**) and gallic acid derivatives (**65**–**69**) so far reported from the genus *Rhynchosia*. Moreover, two polyhydric alcohols such as D-pinitol and D-inositol were also isolated from the leaves of *R. beddomei* (Adinarayana et al. 1979 and Adinarayana et al. 1980c). A unique trioxygenated simple benzophenone (**70**) was reported as a new chemical constituent from the flowers of *R. suaveolens* (Rammohan et al. 2015).

## Sterols

*β*-Sitosterol (**74**), Stigmasteryl galactoside (**75**), Lupeol (**76**) and ergosterol peroxide (**77**) are the four steroid compounds isolated from the whole plant of *R. minima* so far reported in *Rhynchosia* genus (Ahmed et al. 1992; Krishnamurty et al. 1975, Fig. 9).

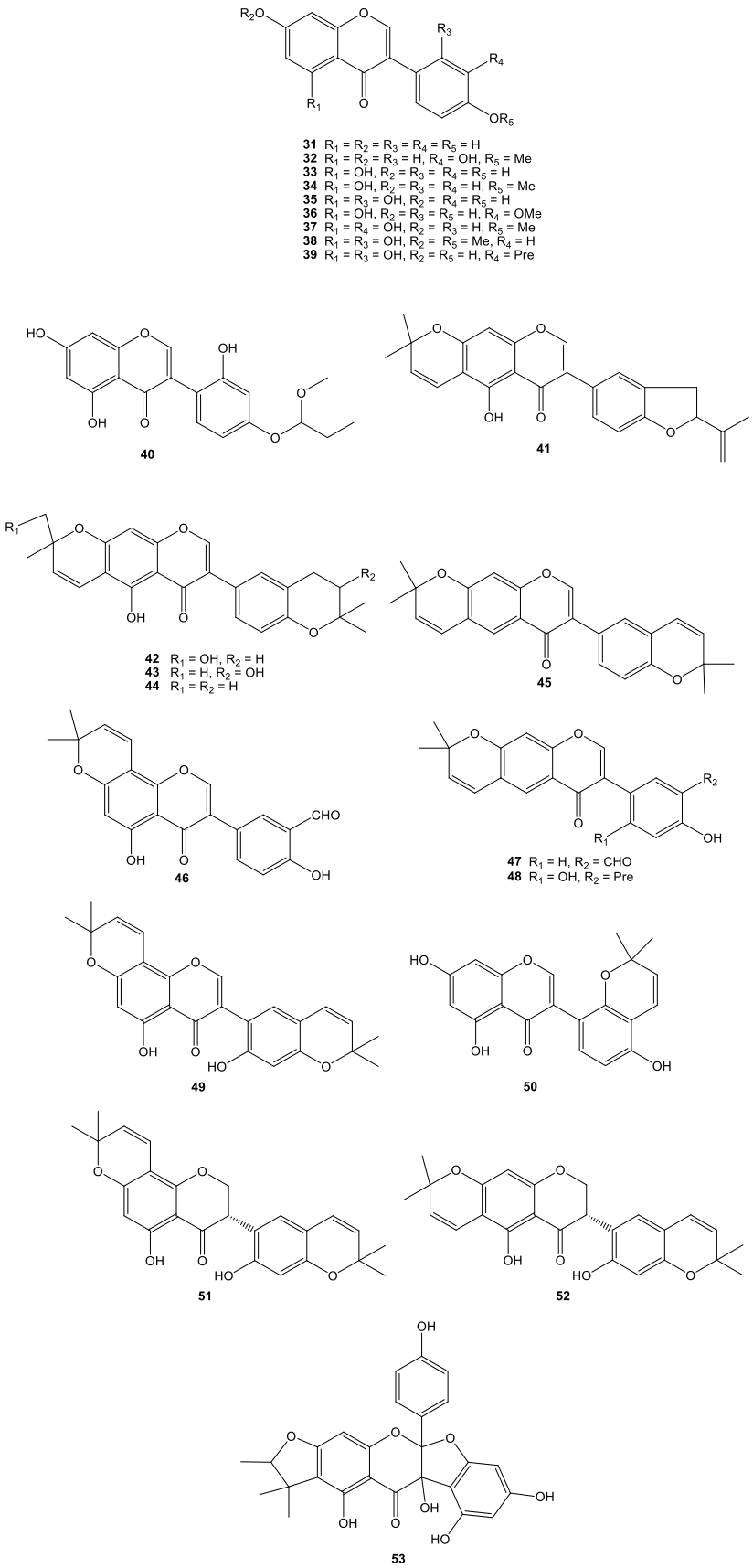



**Fig. 5** Isoflavones (**31**–**50**) and Isoflavanones (**51**–**53**) isolated from the genus *Rhynchosia*

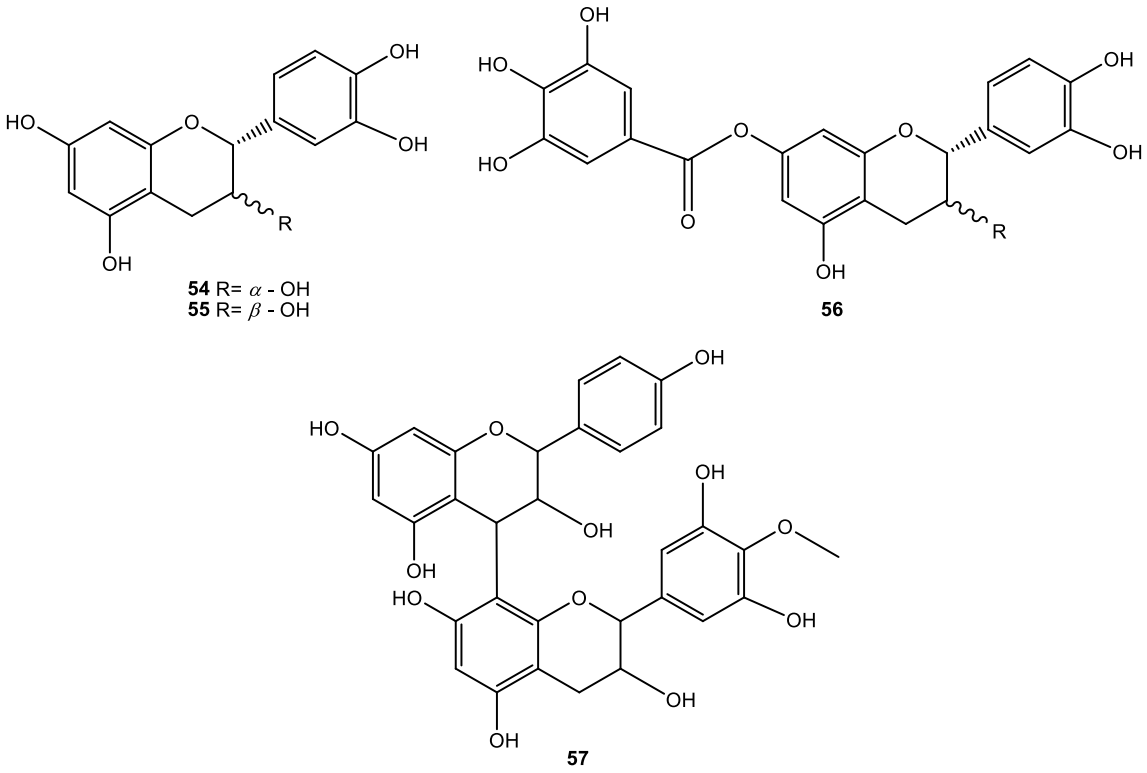



**Fig. 6** Flavan-3-ols (**54**–**57**) isolated from the genus *Rhynchosia*

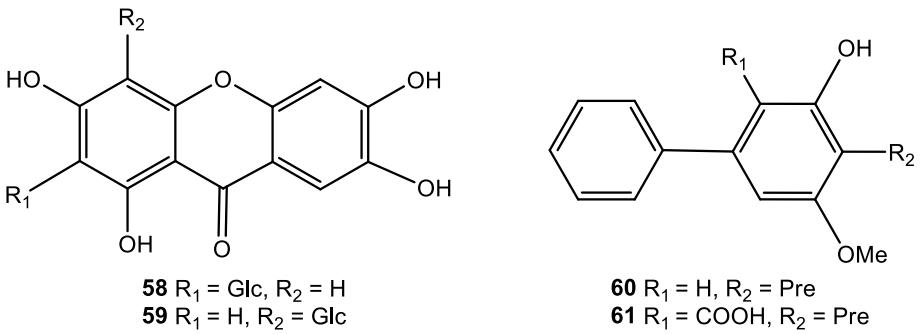



**Fig. 7** Xanthones (**58**–**59**) and biphenyls (**60**–**61**) isolated from the genus *Rhynchosia*

## Pharmacology

Most of the reports are either isolation of chemical constituents or preliminary pharmacological screening of plant extracts of *Rhynchosia* species. There are very few reports are on the bioassay guided isolation of natural compounds and their biological activity studies. In the above section, under traditional uses, we have summarized the activity studies of plant extracts of *Rhynchosia* members and in the current section, the study focusing mostly on stated biological activities of isolated compounds of *Rhynchosia* members. Most of the reported activities are antibacterial, allelopathic activity, anti-angiogenic activity, anti-inflammatory activity, antimycobacterial, antioxidant, antiproliferative, antityrosinase and cytotoxic activity.

### Antioxidant studies

The reactive oxygen species termed as free radicals are formed in human tissue cells during metabolic process, which cause general oxidative damage leading to cellular damage, several types of cancers, inflammation, hypertension and age related diseases. Therefore, many researchers have focused on natural antioxidants because they serve as primary ingredients to balance the oxidative damage against free radicals. Flavonoids are the hugest group of secondary metabolite occuring in plants which show

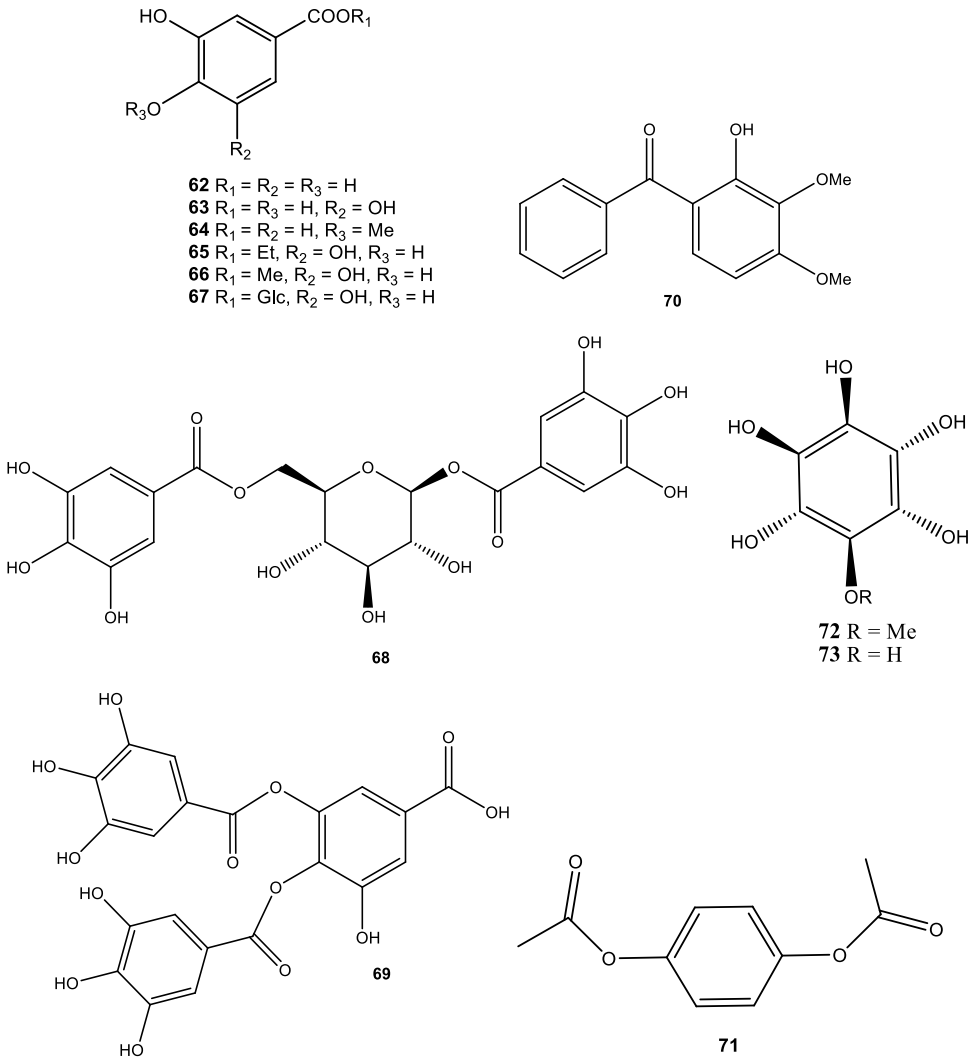



**Fig. 8** Simple polyphenols (**62–73**) isolated from the genus *Rhynchosia*

wide range of therapeutic applications including antioxidant activities. The bioassay-guided isolation of flowers of *Rhynchosia suaveloens* resulted in four flavonoids, isovitexin (**8**), isoorientin (**14**), mangiferin (**58**) and 2-hydroxy-3,4-dimethoxybenzophenone (**70**), which were tested for 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging activity (Rammohan et al. 2015). Among them, compounds **58** and **14** showed prominent antioxidant activity with $IC_{50}$ 51.7 and 57.7 µg/mL, respectively, comparably with positive control ascorbic acid ($IC_{50}$ 34.2 µg/mL). In another study, the aerial parts of *Rhynchosia capitata* were studied through DPPH and nitric oxide antioxidant principles (Praveena et al. 2013) which resulted in five C-glycosylflavanoids namely, vitexin (**7**), isovitexin (**8**), vicenin 2 (**10**), orientin (**13**) and isoorientin (**14**). The *C*-glycosyl flavonoids were studied through density functional theory (DFT) to understand the molecular properties, factors and mechanism of radical scavenging ability. This study declares that the antioxidant activity of *C*-glycosyl flavonoids was exhibited by donating the electrons instead of seizing the free radicals. As a result, this report concludes that the compound vitexin (**7**) acts as good radical scavenger based on quantum chemical computation and theoretical analysis.

## Antimicrobial activity

Recently, four flavonoids namely, isovitexin (**8**), isoorientin (**14**), quercetin-7-*O*-methylether (**21**) and biochanin A (**34**) were isolated from the flowers of *Rhynchosia beddomei* (Rammohan et al. 2019). All the compounds were tested for their antimicrobial activity against gram-positive and gram-negative bacteria and fungi using disc diffusion method. Isoorientin (**14**) and quercetin-7-*O*-methylether (**21**) showed potent inhibition concentrations 20.1 and 15.8 nm; and 20.4 and 15.7 nm, respectively, against *Pseudomonas aeruginosa* and *Candida albicans*. Further, the in silico and Lipinski's rule analysis of the isolated compounds concluded that the compounds **14** and **21** act as prominent antimicrobial agents.

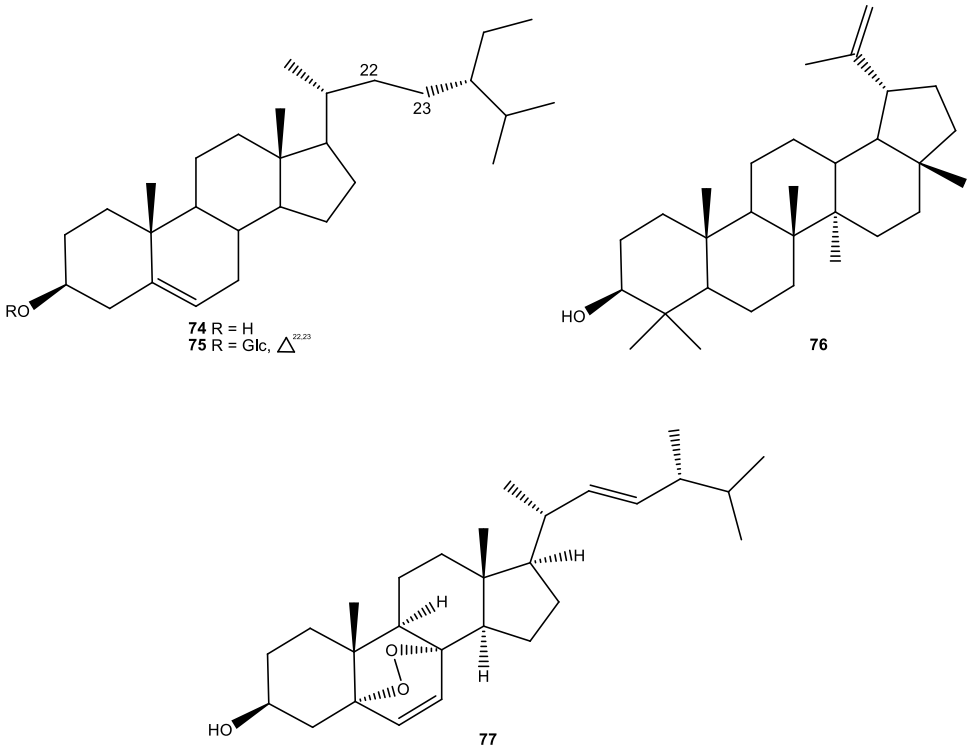



**Fig. 9** Sterols (**74**–**77**) isolated from the genus *Rhynchosia*

## Antimycobacterial activity

The roots of *Rhynchosia precatoria* DC was tested for in vitro inhibitory and bactericidal activity against *Mycobacterium tuberculosis* and *Mycobacterium smegmatis* with redox indicator Alamar Blue (Coronado-Aceves et al. 2017). Further, isolation of dichloromethane fraction of roots of *Rhynchosia precatoria* resulted in six flavonoids, lupinifolin (**26**), lupinifolinol (**30**), cajanone (**48**), precatorin C (**49**), precatorin A (**51**) and precatorin B (**52**). All the isolated compounds, except compound **30,** were screened for antimycobacterial activity. The compounds lupinifolin (**26**) and cajanone (**48**) exhibited highest activity against *Mycobacterium tuberculosis* (*Mtb*) with MIC 31.25 and 62.5 *µg/mL,* respectively. While, the compounds precatorin A (**51**) and cajanone (**48**) showed potent activity *Mycobacterium smegmatis* (*Msm*) with MIC 125 µg/mL (297.29 µM) and 125 µg/mL (295.87 µM), respectively.

## Anti-inflammatory and anti-angiogenic activities

Recent report on the Zebrafish integrated microfractionation of *Rhynchosia viscosa* resulted in five flavonoid compounds such as genistein (**33**), 3′-*O*-methylorobol (**36**), licoisoflavone A (**39**), sophoraisoflavone A (**50**) and a novel new compound, Rhynchoviscin (**53**) (Bohni et al. 2013). Further, the isolated compounds were tested for anti-inflammatory activity using LPS-enhanced leukocyte migration assay. Genistein (**33**) and sophoraisoflavone A (**50**) showed significant inhibition of leukocyte migration with $IC_{50}$ 12.5 and 25 µM, respectively. The other two compounds **36** and **39**, did not show any significant inhibition. Further, the angiogenic activity of extracts and compounds was also carried out using Zebrafish-based vascular outgrowth assay. The compounds, genistein (**33**) and licoisoflavone A (**39**) showed good potency of anti-angiogenic activity with $IC_{50}$ 24.2 and 16.7 µM, respectively (Bohni et al. 2013).

## Antityrosinase activity

The bioassay-guided isolation of roots of *Rhynchosia villosa* resulted in five compounds viz., genistein (**33**), 2′-hydroxygenistein (**35**), cajanin (**38**), catechin (**54**) and 7-*O*-galloylcatechin (**56**). Besides, the isolated compounds exhibited prominent tyrosinase activities (Bohni et al. 2013) such as genistein (31.45 µM), catechin (36.86 µM), cajanin (38.97 µM), galloylcatechin (60.40 µM) and 2′-hydroxygenistein (69.49 µM). The compounds **33** and **38** exhibited the highest tyrosinase inhibitory activity, which may be used as depigmenting agent to treat hyperpigmentation (Bohni et al. 2013).

## Cytotoxic activity

The phytochemical analysis of roots of *Rhynchosia precatoria* DC yielded six compounds such as lupinifolin (**26**), lupinifolinol (**30**), cajanone (**48**), precatorin C (**50**), precatorin A (**51**) and precatorin B (**52**). Further, the roots and

isolated compounds (except lupinifolinol) of *Rhynchosia precatoria* were screened for cytotoxic activity against murine macrophages cells (RAW 264.7) using MTT reduction assay (Coronado-Aceves et al. 2017). The $IC_{50}$ values of the isolated compounds from 13.73 to 160.52 µM indicate that these compounds exhibit less prominent activities and may not be appropriate to treat disease cancer but they may serve as lead molecules for the development of new synthetic molecules.

### Antibacterial activity

The antibacterial activity of ethanol extract of whole plant of *Rhynchosia suaveloens* was studied against *Bacillus subtilis* and *Staphylococcus aureus* pathogens (Khan and Shoeb 1984). The active fraction further purification yields two biphenyls, 4-(3-methyl-but-2-enyl)-5-methoxy-(1,1′-biphenyl)-3-ol (**60**) and 2-carboxy-4-(3-methyl-but-2-enyl)-5-methoxy-(1,1′-biphenyl)-3-ol (**61**). These both biphenyls also showed activity against *Bacillus subtilis* and *Staphylococcus aureus* with minimum inhibitory concentration (MIC) 15.63 and 31.25 µg/mL, respectively.

### Antiproliferative activity

The antiproliferative properties of seeds of *Rhynchosia volubilis* were tested against human gastric adenocarcinoma cells (MK-1), human uterus carcinoma (HeLa) and murine melanoma (B16F10) using MTT assay (Kinjo et al. 2001). The MeOH extract showed potent growth inhibition of MK-1 ($GI_{50}$: 25 µg/ml), HeLa ($GI_{50}$: 30 µg/ml) and B16F10 cells ($GI_{50}$: 8 µg/ml). Further, bioassay-guided isolation of MeOH extract results in six polyphenols, 7-*O*-galloylcatechin (**56**), gallic acid (**63**), methyl gallate (**66**), glucogallin (**67**), 1,6-di-*O*-galloylglucose (**68**) and trigalloylgallic acid (**69**) which showed good inhibition against B16F10 than HeLa and MK-1 cells. Among all the isolates, trigalloylgallic acid showed the highest activity with B16F10, HeLa and MK-1 cells ($GI_{50}$: 2.9, 9.3 and 10 µg/ml) followed by the gallic acid ($GI_{50}$: 7.1, 22 and 19 µg/ml). From the results and structure–antiproliferative activity studies of gallic acid derivatives, it is concluded that the number of galloyl groups and either presence/absence of three adjacent free hydroxyl groups or free carboxyl group for polyphenols are not the prominent reason for weak inhibition of cancer cells by other gallic acid derivatives (**56**, **66**–**68**).

### Allelopathic activity

The essential oil isolated from the roots of *Rhynchosia minima L.* consists of majorly volatile compounds such as α-eudesmol, *trans*-caryophyllene, caryophyllene oxide, 2-allyl-5-*tert*-butylhydroquinone and τ -cadinol (Abd ElGawad et al. 2018). This essential oil showed significant inhibition of *D. aegyptium* and *R. dentatus* germination. Hence, it is recommended as green bio-herbicides such as allelochemicals.

## Conclusions

Though approximately 300 *Rhynchosia* species are distributed all over the world, only 22 species, *R. bracteata*, *R. beddomei*, *R. cana*, *R. capitate*, *R. cyanosperma*, *R. densiflora*, *R. edulis*, *R. heynei*, *R. jacobii*, *R. minima*, *R. precatoria*, *R. pyramidalis*, *R. pseudo-cajan*, *R. rothii*, *R. rufescens*, *R. sericea*, *R. suaveolens*, *R. sublobata*, *R. scarabaeoides*, *R. villosa*, *R. viscosa* and *R. volubilis*, have been investigated so far. Phytochemical studies on the species of this genus led to the isolation of 77 compounds including flavonoids, isoflavonoids, flavan-3-ols, xanthones, biphenyls, simple polyphenols and sterols. Literature survey demonstrated that the genus *Rhynchosia* is a rich source of *C*-glycosylflavonoids and prenylated isoflavonoids. From the published reports on the phytochemical and pharmacological perspective, the genus *Rhynchosia* is a potent source of novel bioactive compounds such as rhynchoviscin, cajanone, genistein, mangiferin, vitexin, precatorin A. The authors of this review believe that insufficient work has been done on this genus and hence, the further work on *Rhynchosia* species may result in novel natural compounds with potent biological activities. Therefore, this review may give a bird view for the future experimental studies in the discovery of new drugs.

**Author contribution statement** The authors AR and DG were outline and collected the literature associated to the review. AR, GMR and BVB were performed manuscript writing and analysis the data. GVZ and DG contributed with their attentive discussions during manuscript preparation.

### Compliance with ethical standards

**Conflict of interest** All the authors declare no conflict of interest.

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